PB-236 377

EVALUATION OF A NOVEL ELECTROPHORETIC SEPARATION METHOD TO REMOVE PYRITIC SULFUR FROM COAL

K. J. Miller, et al

Bureau of Mines

Prepared for:

Environmental Protection Agency

August 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

PB 236 377

BIBLIOGRAPHIC DATA SHEET	1. Report No. BuMines RI 7960	2.

4. Title and Subtitle
Evaluation of a Novel Electrophoretic Separation Method to Remove Pyritic Sulfur From Coal

5. Report Date
August 1974

6. Performing Organization Code

7. Author(s)
K. J. Miller and A. F. Baker

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Pittsburgh Energy Research Center
Bureau of Mines, USDI
4800 Forbes Avenue
Pittsburgh, PA 15213

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Agency Name and Address
Office of Air Programs
Environmental Protection Agency
411 West Chapel Hill Street
Durham, NC 27701

13. Type of Report & Period Covered
Research, FY 1972

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstracts
Electrophoretic mobility measurements of coal and pyrite particles in distilled water revealed a difference between the migration speeds of the two materials toward the anode in a d.c. electric field. This information led to the development of a laboratory electrophoresis column for separating fine pyrite from coal by utilizing the electrokinetic and the specific gravity differences between coal and pyrite. The study demonstrated on a laboratory scale that pyrite and other impurities can be separated from fine coal by electrophoresis using a stage separation technique. After the initial success of the laboratory electrophoresis column, attempts were made to refine the apparatus and several scale-up techniques were considered. This work, however, was halted pending an economic evaluation of the process. Although the evaluation showed the process to be impractical for commercial coal preparation, it is believed that the electrophoresis column may have some application as a laboratory device.

17. Key Words and Document Analysis. 17a. Descriptors
Coal
Pyritic sulfur removal
Electrophoresis
Electrophoretic separation method

17b. Identifiers/Open-Ended Terms

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group 07C, 07D

18. Distribution Statement
Release unlimited by NTIS.

19. Security Class (This Report) UNCLASSIFIED

21. No. of Pages 19

20. Security Class (This Page) UNCLASSIFIED

22. Price 3.00

Report of Investigations 7960

Evaluation of a Novel Electrophoretic Separation Method To Remove Pyritic Sulfur From Coal

By K. J. Miller and A. F. Baker
Pittsburgh Energy Research Center, Pittsburgh, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
Thomas V. Falkie, Director

The work upon which this report is based was funded by the Office of Air Programs of the Environmental Protection Agency.

This publication has been cataloged as follows:

Miller, Kenneth J

Evaluation of a novel electrophoretic separation method to remove pyritic sulfur from coal, by K. J. Miller and A. F. Baker. [Washington] U.S. Bureau of Mines [1974]

14 p. illus., tables. (U.S. Bureau of Mines. Report of investigations 7960)

Based on work funded by the Office of Air Programs of the Environmental Protection Agency.

1. Coal preparation. 2. Coal—Sulphur content. 3. Electrophoresis. I. U.S. Bureau of Mines. II. Baker, Albert F., jt. auth. III. Title. (Series)

TN23.U7 no. 7960 622.06173

U.S. Dept. of the Int. Library

CONTENTS

	Page
Abstract	1
Introduction	1
Experimental procedure and results	2
Summary and conclusions	13

ILLUSTRATIONS

1.	Electrophoretic mobilities of Pittsburgh bed coal and pyrite particles as a function of pH	2
2.	Electrophoretic mobilities of Lower Freeport bed coal, pyrite, and siliceous refuse as a function of pH	2
3.	Electrophoresis column	3
4.	Sectional view of electrophoresis column	4
5.	Electrical current flow in the laboratory electrophoresis column	12
6.	Electrophoretic mobilities of coal and pyrite in distilled water and in tapwater as a function of pH	12

TABLES

1.	Fractionation of sample A of minus 100- plus 325-mesh Lower Freeport bed coal in the 24-inch-long laboratory electrophoresis column with no chemical additives	5
2.	Fractionation of sample A of minus 100- plus 325-mesh Lower Freeport bed coal in laboratory electrophoresis column designed for a three-component fractionation	6
3.	Fractionation of sample B of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column with no chemical additives	7
4.	Fractionation of sample C of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column with no chemical additives	9
5.	Fractionation of sample C of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column in the presence of 10 ppm of sodium hexametaphosphate	10
6.	Fractionation of minus 100- plus 325-mesh Pocahontas No. 3 bed coal in the 9-inch-long laboratory electrophoresis column	11

EVALUATION OF A NOVEL ELECTROPHORETIC SEPARATION METHOD TO REMOVE PYRITIC SULFUR FROM COAL

by

K. J. Miller[1] and A. F. Baker[2]

ABSTRACT

Electrophoretic mobility measurements of coal and pyrite particles in distilled water revealed a difference between the migration speeds of the two materials toward the anode in a dc electric field. This information led to the development of a laboratory electrophoresis column for separating fine pyrite from coal by utilizing the electrokinetic and the specific gravity differences between coal and pyrite. The study demonstrated on a laboratory scale that pyrite and other impurities can be separated from fine coal by electrophoresis using a stage separation technique.

In a cost analysis, electrical power for electrophoresis was extrapolated to about $1 per ton of clean coal product. But, since the only successful tests ever made were in the laboratory with prewashed samples of minus 100-plus 325-mesh coal in distilled water, the cost figure derived is not representative of conditions prevalent in commercial coal cleaning operations. True conditions would reflect costs many times as great.

In the course of the work, several scale-up techniques were considered but their feasibility became academic in view of the physical and economic problems associated with electrophoretic separation of pyrite from coal. Although the process and apparatus were finally deemed impractical for commercial coal preparation, the electrophoresis column may have some application as a laboratory device.

INTRODUCTION

Separating the pyritic sulfur from coal before it is burned is a recognized means of combating air pollution; however, to maximize liberation of pyritic sulfur the coal must be crushed to such a fine size that conventional coal washing techniques become ineffective. Specific gravity separations are not suitable because the fine particles produced by crushing settle slowly in heavy liquids; and conventional froth flotation suffers because of the tendency for the unliberated or very fine-size pyrite to float with the coal.

---

[1] Supervisory physical science technician.
[2] Research physicist.

Therefore, the Bureau of Mines, with funds provided by the Office of Air Programs of the Environmental Protection Agency, has been investigating a novel method, one which utilizes electrophoresis to separate pyrite from coal.

Electrophoresis is defined as the migration of electrokinetically charged particles in a liquid toward an electrode of opposite charge in a dc electrical field. The migration speed is directly proportional to the magnitude of the electrokinetic charge, or zeta potential, of the particles and to the applied voltage; it is inversely proportional to the distance between the electrodes.

Electrophoresis has been used in the laboratory to fractionate materials as diverse as blood, bacteria, natural clays, and colloidal carbon, but little effort has been directed toward the separation of relatively large particles of widely varying specific gravities such as those encountered in coal beneficiation. In view of the increased concern for cleaner air, and the obvious need for better pyrite removal equipment, it was felt that an electrophoretic technique warranted investigation as a possible means for removing the pyritic sulfur from fine size coal.

EXPERIMENTAL PROCEDURE AND RESULTS

Electrophoretic mobility measurements of Pittsburgh bed coal and pyrite, and Lower Freeport bed coal, pyrite, and siliceous refuse were made with a Zeta-Meter[3] (figs. 1 and 2). These tests showed that both coal and pyrite

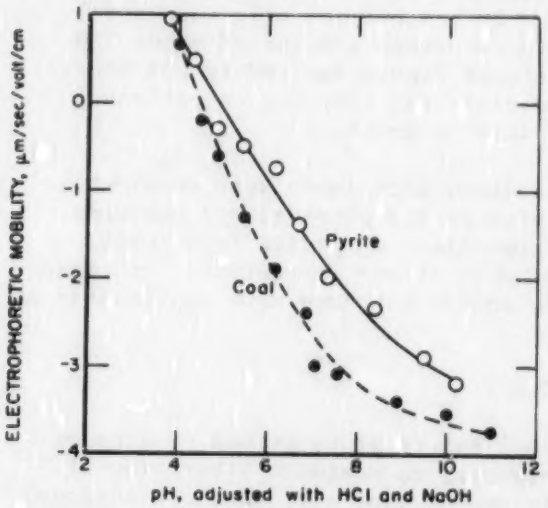


FIGURE 1. - Electrophoretic mobilities of Pittsburgh bed coal and pyrite particles as a function of pH.

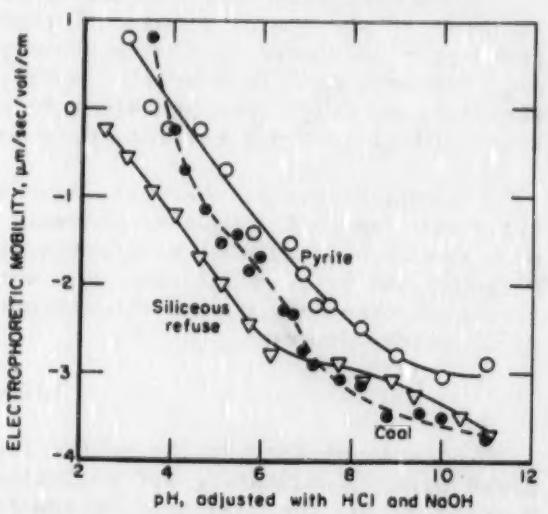


FIGURE 2. - Electrophoretic mobilities of Lower Freeport bed coal, pyrite, and siliceous refuse as a function of pH.

[3]Reference to specific brands of equipment does not imply endorsement by the Bureau of Mines.

were negatively charged above pH 4, but that coal was more negative. With this information as a basis, a plastic electrophoresis cell was constructed to separate pyrite from fine coal. The apparatus is shown assembled and diagrammatically in figures 3 and 4. With the electrophoresis column it was demonstrated on a laboratory scale that pyrite and other impurities, such as siliceous refuse, can be separated from fine coal by electrophoresis. But,

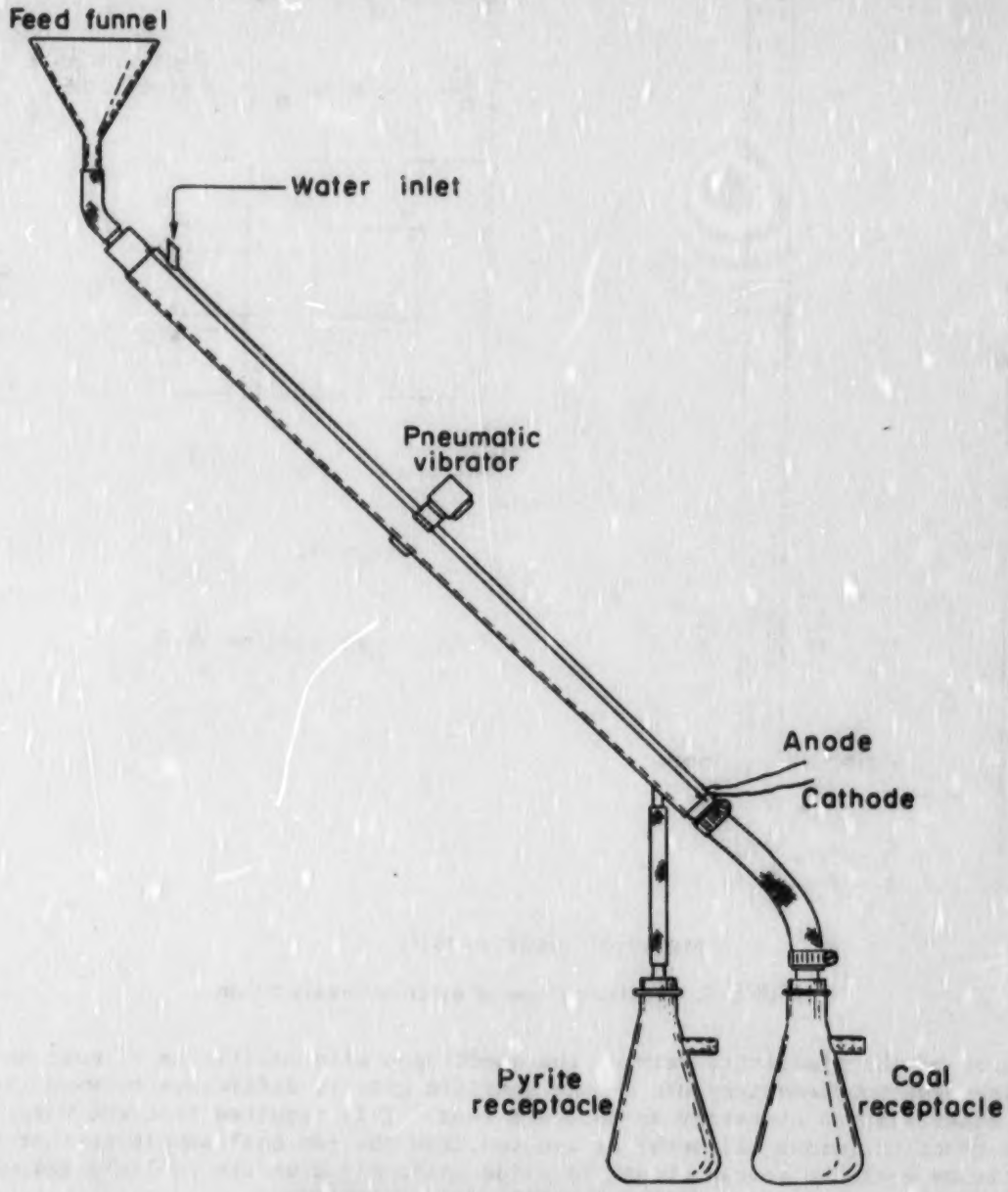
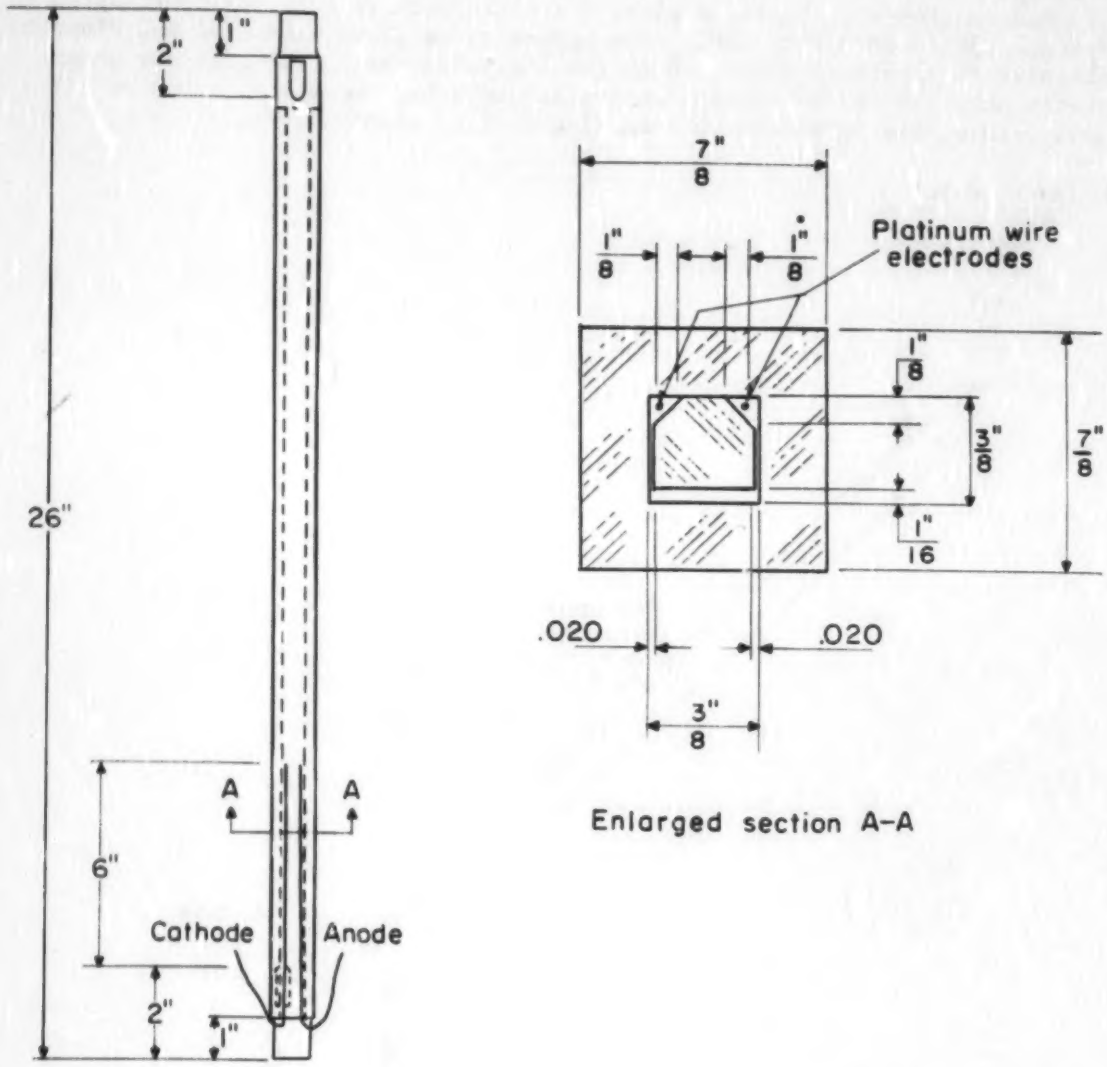


FIGURE 3. - Electrophoresis column.



Material: clear plastic

FIGURE 4. - Sectional view of electrophoresis column.

because of the similarity between the electrophoretic mobilities of coal and pyrite, the supplementary use of the specific gravity difference between the two materials was necessary to separate them. This required that the very fine fraction (minus 325-mesh) be removed from the raw coal sample so that the particles would be coarse enough to slide uniformly down the inclined column and not be carried by the flow of water.

As test 3 of table 1 shows, to achieve a satisfactory separation it was necessary to employ a stage separation technique whereby the low-sulfur refuse and the coal would be attracted separately toward the anode in two passes through the column, the second at a higher voltage than the first. Also, the feed slurries had to be dilute (1 to 2 percent solids) so that the particles were discrete and easily separable. The development of the electrophoresis column and the early results were reported in a previous Bureau of Mines publication.[4]

TABLE 1. - Fractionation of sample A of minus 100- plus 325-mesh Lower Freeport bed coal in the 24-inch-long laboratory electrophoresis column with no chemical additives

Test	Voltage, volts dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur	Weight	Ash	Pyritic sulfur	Total sulfur
1	500	5.0	Coal.....	94.3	13.2	1.01	1.61	94.3	13.2	1.01	1.61
			Pyrite.....	5.7	45.0	19.73	19.95	100.0	15.0	2.23	2.66
2	400	2.0	Coal.....	55.6	17.0	.34	1.07	55.6	17.0	.34	1.07
			Pyrite.....	44.4	14.8	4.63	5.58	100.0	16.0	2.24	3.07
3	250	1.5	Coal 1st pass	13.8	44.5	.38	.61	13.8	44.5	.38	.61
	500	5.0	Coal 2d pass.	17.3	8.9	.62	1.38	91.1	14.3	.58	1.26
			Pyrite.....	8.9	44.8	21.00	22.65	100.0	17.0	2.40	3.17

After successful removal of both pyritic and siliceous refuse from a coal sample, several revised electrophoresis cells were constructed. One cell was designed to fractionate a raw coal sample into three distinct components--siliceous refuse, coal, and pyritic refuse--in one pass at a constant voltage; another cell was equipped with a membrane to separate the electrode chambers from the main chamber so that gas bubbles and convection currents originating at the electrodes would not disturb the smooth flow of particles down the inclined column. In preliminary tests, serious mechanical flaws were found in both cells necessitating repairs or reconstruction. These repairs, however, were not carried out because other problems, both physical and economic, became more immediate than refinement of the apparatus. It was possible, however, to conduct a few tests with the cell designed to make a three-component fractionation. Results of these tests are given in table 2.

For studying the physical and economic limitations of electrophoresis as a coal cleaning method, the earlier column shown in figures 3 and 4 was employed; except that it was shortened from 24 inches to 9 inches. A series of tests was run with this modified column at varied lateral slopes and applied voltages. The longitudinal slope was fixed at 45 degrees. The coal used in the tests was a sample of Lower Freeport bed coal (sample B) sized minus 100- plus 325-mesh. The pH during the tests was about 6.2. The results are shown in table 3.

[4]Miller, K. J., and A. F. Baker. Electrophoretic-Specific Gravity Separation of Pyrite From Coal. BuMines RI 7440, 1970, 12 pp.

TABLE 2. - Fractionation of sample A of minus 100- plus 325-mesh Lower Freeport bed coal in laboratory electrophoresis column designed for a three-component fractionation

Lateral slope, degrees	Voltage, volts dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur	Weight	Ash	Pyritic sulfur	Total sulfur
[1]3	500	10.0	1	7.6	([2])	([2])	0.72	7.6	([2])	([2])	0.72
			2	78.3	8.7	0.67	1.31	85.9	([2])	([2])	1.26
			3	14.1	([2])	([2])	13.90	100.0	([2])	([2])	3.04
3	500	7.5	1	7.4	([2])	([2])	1.03	7.4	([2])	([2])	1.03
			2	67.0	13.4	.62	1.19	74.4	([2])	([2])	1.17
			3	25.6	([2])	([2])	9.14	100.0	([2])	([2])	3.21
4	500	4.0	1	3.3	([2])	([2])	.91	3.3	([2])	([2])	.91
			2	62.7	13.4	.64	1.27	66.0	([2])	([2])	1.25
			3	34.0	14.6	5.88	6.14	100.0	([2])	([2])	2.91
[3]4	500	2.0	1	4.9	([2])	([2])	.66	4.9	([2])	([2])	.66
			2	49.4	13.8	.73	1.19	54.3	([2])	([2])	1.14
			3	45.7	11.6	3.48	4.57	100.0	([2])	([2])	2.71
[3]6	500	2.0	1	2.9	NA	NA	NA	2.9	NA	NA	NA
			2	15.8	NA	NA	NA	18.7	NA	NA	NA
			3	81.3	NA	NA	NA	100.0	NA	NA	NA
[3]8	500	1.5	1	2.5	NA	NA	NA	2.5	NA	NA	NA
			2	6.4	NA	NA	NA	8.9	NA	NA	NA
			3	91.1	NA	NA	NA	100.0	NA	NA	NA

NA Recovery insufficient to justify analysis.
[1]Slurry flow rate 20 ml/min instead of usual 50 ml/min.
[2]Insufficient material for analysis.
[3]Coal sample washed in distilled water prior to test.

TABLE 3. - Fractionation of sample B of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column with no chemical additives

Lateral slope, degrees	Voltage, volts, dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur	Weight	Ash	Pyritic sulfur	Total sulfur
6	100	0.4	Coal	24.8	[1]	0.29	[1]	24.8	[1]	0.29	[1]
			Pyrite	75.2	15.8	1.99	3.02	100.0	[1]	1.57	[1]
	200	1.0	Coal	34.0	12.7	.45	1.39	34.0	12.7	.45	1.39
			Pyrite	66.0	13.7	2.65	3.68	100.0	13.4	1.90	2.90
	300	1.0	Coal	41.9	[1]	.24	[1]	41.9	[1]	.24	[1]
			Pyrite	58.1	12.5	3.11	3.82	100.0	[1]	1.91	[1]
	400	2.0	Coal	79.6	12.3	.47	1.63	79.6	12.3	.47	1.63
			Pyrite	20.4	[1]	7.05	[1]	100.0	[1]	1.81	[1]
	500	2.5	Coal	97.7	12.4	1.41	2.10	94.7	12.4	1.41	2.10
			Pyrite	5.3	25.7	[1]	[1]	100.0	13.1	[1]	[1]
8	400	1.8	Coal	56.5	13.4	.49	1.13	56.5	13.4	.49	1.13
			Pyrite	43.5	13.1	3.52	4.06	100.0	13.3	1.81	2.40
	500	2.0	Coal	91.6	14.6	.74	1.49	91.6	14.6	.74	1.49
			Pyrite	8.4	[1]	16.39	[1]	100.0	[1]	2.05	[1]
10	100	.4	Coal	16.2	[1]	.39	[1]	16.2	[1]	.39	[1]
			Pyrite	83.8	15.0	2.16	3.10	100.0	[1]	1.87	[1]
	200	1.0	Coal	19.3	12.1	.34	1.11	19.3	12.1	.34	1.11
			Pyrite	80.7	13.7	2.14	2.94	100.0	13.4	1.79	2.59
	300	1.5	Coal	27.2	18.4	[1]	1.03	27.2	18.4	[1]	1.03
			Pyrite	72.8	11.1	2.31	2.79	100.0	13.1	[1]	2.31
	400	2.0	Coal	57.3	14.1	.40	1.03	57.3	14.1	.40	1.03
			Pyrite	42.7	14.4	[1]	4.34	100.0	14.2	[1]	2.44
	500	3.5	Coal	96.6	12.7	1.06	1.75	96.6	12.7	1.06	1.75
			Pyrite	3.4	[1]	[1]	[1]	100.0	[1]	[1]	[1]
12	100	.5	Coal	9.1	[1]	.12	[1]	9.1	[1]	.12	[1]
			Pyrite	90.9	13.3	1.95	2.79	100.0	[1]	1.78	[1]
	200	.8	Coal	15.6	[1]	.44	[1]	15.6	[1]	.44	[1]
			Pyrite	84.4	11.4	2.28	2.76	100.0	[1]	1.99	[1]
	300	1.8	Coal	27.0	[1]	.13	.94	27.0	[1]	.13	.94
			Pyrite	73.0	12.4	2.49	3.12	100.0	[1]	1.85	2.53
	400	1.5	Coal	51.2	13.8	.29	1.03	51.2	13.8	.29	1.13
			Pyrite	48.8	14.0	3.86	4.79	100.0	13.9	2.03	2.86
	500	2.3	Coal	67.1	11.7	.42	1.13	67.1	13.7	.42	1.13
			Pyrite	32.9	18.8	4.56	5.28	100.0	14.0	1.78	2.50

[1] Insufficient material for analysis.

A fresh sample of Lower Freeport bed coal (sample C) was obtained and sized to minus 100- plus 325-mesh. A series of tests similar to the aforementioned series was run with this sample. The pH during the tests was about 6.6. These results are shown in table 4. A comparison of the data from tables 3 and 4 reveals that sample C was more difficult to fractionate than sample B; recoveries were poorer because less coal was attracted toward the anodic side of the column. As a result, a second series of tests was done with sample C in which a small quantity of sodium hexametaphosphate, a highly anionic reagent, was added to the slurries. This increased the pH to about 7. These results are shown in table 5. A comparison of the data from tables 4 and 5 shows that recoveries increased substantially because of this reagent addition.

In addition to the tests with Lower Freeport bed coal, several tests were run with a Pocahontas No. 3 bed coal sample. The tests were run with no additives and with 10 ppm of sodium hexametaphosphate. The pH's were 6.2 and 6.5, respectively. The results are shown in table 6.

In all of the tests shown in tables 4, 5, and 6, the material recovered in the coal receptacle had a disproportionately high ash content due to the anodic attraction and concentration of siliceous refuse. This was especially true when recoveries were poor, and it further demonstrates the need for a stage separation technique as stated earlier and shown in table 1.

All of the tests shown in tables 4, 5, and 6 were done with slurries of 1 percent solids fed at a rate of about 50 milliliters per minute (1/2 gram of solids per minute). Greater feed rates were attempted, but the discreteness of particles necessary for a distinct electrophoretic-specific gravity separation in this particular column could not be provided at rates in excess of about 1/2 gram of solids per minute. At feed rates greater than 1/2 gram of solids per minute the particle stream sliding down the column floor was too wide to permit a separation, and bridging of the particles occurred between the column walls. At slurry flow rates greater than 50 milliliters per minute, the particles were carried along by the flow of water, thus negating the effect of electrophoresis. For these reasons the rate of 50 milliliters per minute and a 1-percent solids slurry was adopted as a standard insuring an ever-changing water supply and a narrow particle band. To achieve the controlled feed rate, a needle valve and a flowmeter were installed in the water outlet line of the coal receptacle.

Using data from these tests and assuming that a two-stage separation is employed, the electrical power consumption per ton of feed was extrapolated to about 80 kilowatt-hours. And, assuming a cost of about $0.01 per kilowatt-hour with a recovery of 80 percent, the electrical power cost alone was calculated to be about $1.00 per ton of clean coal product. This projected cost of electricity was based on a direct scale-up of the laboratory equipment which uses distilled water and minus 100- plus 325-mesh coal washed in distilled water, and it does not take into account any energy except that used for electrophoresis.

TABLE 4. - Fractionation of sample C of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column with no chemical additives

Lateral slope, degrees	Voltage, volts dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur	Weight	Ash	Pyritic sulfur	Total sulfur
4	200	1.8	Coal.....	27.2	20.2	0.30	0.95	27.2	20.2	0.30	0.95
			Pyrite...	72.8	12.5	2.34	3.34	100.0	14.6	1.79	2.69
	300	3.5	Coal.....	52.2	18.8	.64	1.35	52.2	18.8	.64	1.35
			Pyrite...	47.8	13.1	4.17	5.12	100.0	16.1	2.33	3.15
	400	5.0	Coal.....	56.7	18.8	2.01	2.30	56.7	18.8	2.01	2.30
			Pyrite...	43.3	9.9	2.66	2.94	100.0	14.9	2.29	2.58
	500	4.5	Coal.....	56.2	21.2	2.44	2.97	56.2	21.2	2.44	2.97
			Pyrite...	43.8	9.9	2.37	2.98	100.0	16.2	2.41	2.97
6	200	1.0	Coal.....	11.6	([1])	.21	([1])	11.6	([1])	.21	([1])
			Pyrite...	88.4	15.8	2.79	3.39	100.0	([1])	2.49	([1])
	300	2.5	Coal.....	26.0	([1])	.36	.90	26.0	([1])	.36	.90
			Pyrite...	74.0	11.9	2.99	3.77	100.0	([1])	2.31	3.02
	400	3.5	Coal.....	40.1	([1])	.54	1.18	40.1	([1])	.54	1.18
			Pyrite...	59.9	12.0	3.97	4.86	100.0	([1])	2.59	3.38
	500	5.5	Coal.....	52.2	18.8	1.55	2.21	52.2	18.8	1.55	2.21
			Pyrite...	47.8	10.5	2.99	3.57	100.0	14.8	2.24	2.86
8	200	1.8	Coal.....	8.8	([1])	.41	([1])	8.8	([1])	.41	([1])
			Pyrite...	91.2	14.9	2.34	2.89	100.0	([1])	2.17	([1])
	300	1.8	Coal.....	20.0	([1])	.25	([1])	20.0	([1])	.25	([1])
			Pyrite...	80.0	12.1	2.70	3.25	100.0	([1])	2.21	([1])
	400	4.0	Coal.....	28.1	([1])	.47	.90	28.1	([1])	.47	.90
			Pyrite...	71.9	11.6	3.28	3.94	100.0	([1])	2.49	3.09
	500	4.0	Coal.....	42.6	([1])	2.32	2.88	42.6	([1])	2.32	2.88
			Pyrite....	57.4	10.7	2.11	2.79	100.0	([1])	2.20	2.83

[1] Insufficient material for analysis.

TABLE 5. - Fractionation of sample C of minus 100- plus 325-mesh Lower Freeport bed coal in the 9-inch-long laboratory electrophoresis column in the presence of 10 ppm of sodium hexametaphosphate

Lateral slope, degrees	Voltage, volts dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur	Weight	Ash	Pyritic sulfur	Total sulfur
4	200	9.5	Coal.....	44.8	17.1	0.54	1.19	44.8	17.1	0.54	1.19
			Pyrite...	55.2	14.9	4.59	5.01	100.0	15.9	2.78	3.30
	300	10.5	Coal.....	56.8	17.1	.94	1.49	56.8	17.1	.94	1.49
			Pyrite...	43.2	14.8	4.37	4.97	100.0	16.1	2.42	2.99
	400	12.0	Coal.....	73.7	13.4	.83	1.61	73.7	13.4	.83	1.61
			Pyrite...	26.3	16.2	5.16	5.79	100.0	14.1	1.97	2.71
	500	18.0	Coal.....	85.1	13.7	1.47	1.99	85.1	13.7	1.47	1.99
			Pyrite...	14.9	([1])	5.94	6.44	100.0	([1])	2.14	2.65
6	200	10.5	Coal.....	36.7	16.1	.46	1.09	36.7	16.1	.46	1.09
			Pyrite...	63.3	12.7	3.05	3.70	100.0	13.9	2.10	2.74
	300	12.0	Coal.....	50.0	17.0	.94	1.63	50.0	17.0	.94	1.63
			Pyrite...	50.0	13.4	3.78	4.02	100.0	15.2	2.36	2.82
	400	14.5	Coal.....	73.2	14.0	1.00	1.57	73.2	14.0	1.00	1.57
			Pyrite...	26.8	([1])	6.09	6.72	100.0	([1])	2.36	2.95
	500	18.0	Coal.....	73.6	15.3	1.68	2.10	73.6	15.3	1.68	2.10
			Pyrite...	26.4	([1])	4.11	4.84	100.0	([1])	2.32	2.82
8	200	9.0	Coal.....	28.7	14.7	.48	1.11	28.7	14.7	.48	1.11
			Pyrite...	71.3	([1])	2.91	3.62	100.0	([1])	2.21	2.90
	300	12.0	Coal.....	38.5	17.8	.52	1.11	38.5	17.8	.52	1.11
			Pyrite...	61.5	14.0	3.55	3.94	100.0	15.5	2.38	2.85
	400	16.0	Coal.....	59.7	15.3	.90	1.49	59.7	15.3	.90	1.49
			Pyrite...	40.3	15.4	5.00	5.56	100.0	15.3	2.55	3.13
	500	18.0	Coal.....	75.9	15.8	1.47	2.09	75.9	15.8	1.47	2.09
			Pyrite...	24.1	([1])	5.67	6.46	100.0	([1])	2.48	3.14

[1] Insufficient material for analysis.

TABLE 6. - Fractionation of minus 100- plus 325-mesh Pocahontas No. 3 bed coal in the 9-inch-long laboratory electrophoresis column

Lateral slope, degrees	Voltage, volts, dc	Average current, milliamps	Receptacle	Direct data, percent				Cumulative data, percent			
				Weight	Ash	Pyritic sulfur	Total sulfur[1]	Weight	Ash	Pyritic sulfur	Total sulfur
[1]6	400	2.5	Coal.....	26.2	14.2	0.03	0.68	26.2	14.2	0.02	0.68
			Pyrite....	73.8	5.7	.07	.64	100.0	7.9	.06	.65
	500	3.0	Coal.....	36.3	12.7	.02	.58	36.3	12.7	.02	.58
			Pyrite....	63.7	4.4	.06	.78	100.0	7.4	.05	.71
[2]6	400	14.5	Coal.....	61.5	7.9	.03	.72	61.5	7.9	.03	.72
			Pyrite....	38.5	6.2	.07	.64	100.0	7.2	.05	.69
	500	17.0	Coal.....	64.9	8.2	.04	.60	64.9	8.2	.04	.60
			Pyrite....	35.1	6.0	.07	.68	100.0	7.4	.05	.63

[1]With no chemical additives.
[2]With 10 ppm of sodium hexametaphosphate.

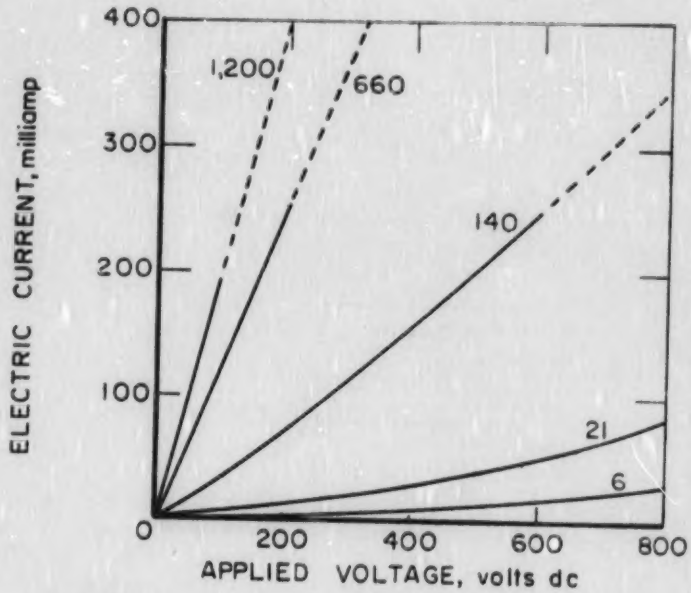


FIGURE 5. - Electrical current flow in the laboratory electrophoresis column as a function of applied voltage in slurries of specific conductance 6, 21, 140, 660, and 1,200 micromhos/cm.

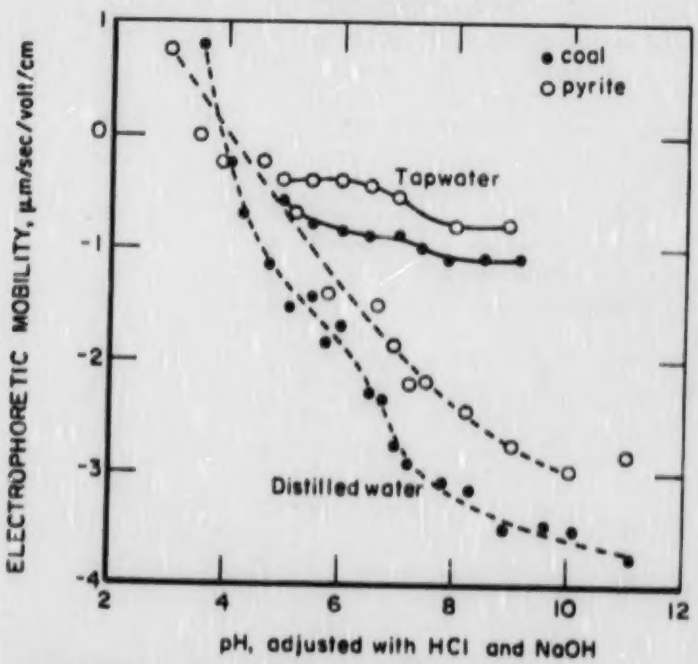


FIGURE 6. - Electrophoretic mobilities of coal and pyrite in distilled water and in tapwater as a function of pH.

Several tests were attempted with slurries of high electrical conductivity, but they proved impossible to run with the laboratory electrophoresis apparatus. At specific conductivities above 20 micromhos per centimeter (the tapwater has a specific conductivity of 300 to 600 micromhos per centimeter) convection became violent, and gas bubble evolution was so profuse that the bubbles could not be contained in the electrode chambers. Figure 5 relates specific conductance to electrical current flow in the electrophoresis column.

The electrophoretic mobilities versus pH of Lower Freeport bed coal and pyrite shown in figure 2 were measured in distilled water. Unfortunately, as figure 6 shows, the electrophoretic mobilities of the same coal and pyrite in tapwater were significantly less. This result was probably due to multivalent metal ions such as calcium (Ca^{++}) and iron (Fe^{+++}), which reduced the negative zeta potential of the particles.

Increasing the negative zeta potential and, therefore, the electrophoretic mobility of the coal particles with chemical reagents was tried, but these tests were not successful because the electrical conductivity of the slurries generally increased more than the electrophoretic mobility of the particles.

Besides, the reagents tested were not very selective in their absorption. That is, they increased the negative electrokinetic charge of the pyrite as well as that of the coal particles.

In an attempt to reduce the electrical power consumption of the electrophoresis column, several tests were tried with very short electrodes (less than 1 inch), but this required that the voltage be proportionately increased so that no advantage was gained. In fact, such high voltages were required that the particles appeared to be blown across the column creating a diffuse, turbulent particle stream.

SUMMARY AND CONCLUSIONS

This investigation has demonstrated on a laboratory scale that pyrite and other impurities, such as siliceous refuse, can be separated from fine coal by an electrophoretic separation method. The tests were done with dilute slurries composed of distilled water and minus 100- plus 325-mesh coal washed in distilled water. The electric power cost given in the Experimental Procedures and Results section of this report was based on these laboratory test procedures. A more realistic economic appraisal using an unwashed coal of less discriminate size consist and water generally associated with a coal slurry would reveal a cost at least several hundred, and possibly several thousand times as great--if, in fact, such a test could be made.

Even if the physical limitations such as gassing at the electrodes, severe convection currents, and electrolytic destruction of any but platinum electrodes could be overcome, and the economics ignored, it would be difficult to separate coal from pyrite at the low electrophoretic mobilities encountered in tapwater (fig. 6).

The electrokinetic charges (zeta potentials) of coal and pyrite in distilled water are weak (about minus 30 millivolts and minus 20 millivolts, respectively) compared to the disruptive effects of convection. The average speeds of migration of suspended particles toward the anode at 500 volts with 1 centimeter electrode spacing are only about 1.5 millimeters per second for coal and 1.0 millimeter per second for pyrite. In tapwater, or any water containing multivalent metal ions such as iron or calcium, the migration speeds are somewhat less. Furthermore, these speeds apply to colloidal particles suspended in water. The speeds of migration of the relatively large particles used in the electrophoresis column would be even less because of the friction of the column floor and the fact that the column is inclined about 10 degrees to one side.

Before the severe limitations to electrophoretic coal-pyrite separation became known, several scale-up techniques were considered. A direct scale-up was promptly abandoned because it would require a proportionate increase in applied voltage to compensate for the greater electrode spacing. Joule heating and convection would then become extremely troublesome for, with the scale-up, the dissipation of internally generated heat would become very difficult.

A battery of small cells appeared more promising, but the complexity of such an apparatus would be prohibitive unless some degree of scale-up could be made on each of the cells in the battery. For example, a battery of cells large enough to clean a ton of coal per hour would require about 30,000 units the size of our laboratory device and about 5-1/2 miles of electrode wire. Besides, the problems with particle size restriction and electrical current flow would still exist.

In view of these numerous limitations, it seems unrealistic to set up a direct cost per unit amount of coal cleaned based on tests with the laboratory device. When such a cost analysis is projected to the plant scale, it requires the visualization of a direct scale-up of the laboratory electrophoresis column, or alternatively, a huge battery of small cells. Neither prospect appears feasible. Hence, patent processing by the U.S. Department of the Interior does not appear to be warranted.

It is our opinion that the ectrophoresis method described is uneconomical and impractical for commercial coal preparation. It might, however, have some application as a laboratory technique for separating minerals with different electrokinetic charges.

INT.-BU.OF MINES,PGH.,PA. 19599